

Associations between Executive Function and Type of Sedentary Behavior in Older Adults with
and without Alzheimer's Disease

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and without Alzheimer's Disease

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Abstract

Objectives: Sedentary behavior may be both a cause and a consequence of cognitive decline in older adults. While previous literature provides plausible explanations for the relationship between sedentary behavior and cognition, research examining the directionality of this relationship is inconclusive. Little is known about how modality of sedentary behavior (e.g., screen time and non-screen time) is related to cognition. Individuals with dementia, a population known to have executive function impairment, have been found to sit more than their age and sex based counterparts. Therefore, the primary purpose of the present study was to investigate the potential bi-directional relationship between types of sedentary behavior and executive function in older adults with and without Alzheimer's disease.

Methods: One hundred community-dwelling older adults were recruited from an existing data registry at the University of Kansas Alzheimer's Disease Center. In the present study, sedentary behavior data were collected over a one-week period using both objective (body worn inclinometers) and subjective methods (self-report diaries). Based on combining objective with subjective data, sedentary behavior modality was categorized into seven distinct categories which included screen based behaviors (television watching, computer use, multiple types of screen use, and other types of screen use), non-screen based behaviors, a combination of screen and non-screen behaviors, and unknown sedentary behaviors. Executive function was measured by creating a factor score comprised of four tests of executive function administered in a battery of neuropsychological tests. Linear stepwise regressions were used to assess directionality of the relationship between sedentary behavior and cognitive performance with age, sex, race, education level, body mass index, and dementia status used as covariates.

Results: Only one type of sedentary behavior, the engagement in a combination of both screen and non-screen activities during a given 30-minute period, uniquely predicted higher executive function scores. Higher executive function scores also predicted more time spent in sedentary behavior periods that were made of up a combination of both screen and non-screen activities. Executive function performance contributed a larger degree of variance explained to sedentary behavior made up of a combination of both screen and non-screen activities than this form of sedentary behavior contributed to executive function.

Conclusion: These findings suggest that older adults with executive function deficits may not be able to engage in periods of sedentary behavior that are made up of a combination of both screen and non-screen activities. The maintenance of executive function abilities may help engagement in this form in sedentary behavior. Our results suggest that interventions to decrease sedentary behavior in older adults may need to consider the type of sedentary behavior that they aim to change as well as the person's executive function ability.

Keywords: cognition, executive function, sedentary behavior, modality, inclinometry, older adults, Alzheimer's disease

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Introduction

Sedentary behavior, defined as “any waking behavior characterized by an energy expenditure ≤ 1.5 metabolic equivalents (METs), while in a sitting, reclining or lying posture,” (Tremblay, 2017) is emerging as an important risk factor for deleterious health outcomes. Broadly, studies have linked sedentary behavior, independent of effects of physical activity, to adverse health outcomes such as poor metabolism, bone mineral content, and vascular health across the lifespan (Hamilton, 2008; Tremblay, 2010). These findings are especially important for older adults, who, as a population, engage in large amounts of sedentary behavior.

The use of both subjective and objective measures of sedentary behavior in older adults has shown that older adults spend a substantial portion of their waking day in sedentary behavior. A systematic review of self-reported measures of sedentary behavior found that across six countries, 78% of older adults sit for more than 3 hours a day (Harvey, 2013). On average, across seven studies, 58.9% of older adults reported sitting for more than 4 hours a day, 26.6% reported sitting over 6 hours a day, and 5.0% reported sitting over 10 hours a day (Harvey, 2013). These findings are likely an underestimation of the total amount of sedentary time that older adults engage in as these studies use self-report measures (Copeland, 2017).

Objective measures of sedentary behavior in older adults suggest that older adults spend the majority of their waking hours in sedentary behavior. Data obtained from the National Health and Nutrition Survey (NHANES) using data from body-worn accelerometers found that older adults aged 60-85 years old, spent almost 60% of their waking hours, or more than 8 hours a day, in sedentary behaviors (Matthews, 2008). These researchers further found that across the lifespan, adults aged 70-85 were the most sedentary group (Matthews, 2008). Other studies using objective measures of sedentary behavior have found similar numbers. For example, a recent

analysis using accelerometry found that depending on the cut points used, older adult women spent somewhere between 62% and 86% of their day in sedentary time (Gorman, 2014) while data from two waves of the NHANES found that U.S. adults aged 60 years or older spent 8.5 hours a day in sedentary behaviors (Evenson, 2011).

Because of the large amounts of sedentary behavior and the associated negative health consequences in older adults, it is crucial to understand the ways in which sedentary behavior can be modified. It is therefore necessary to understand more about the correlates of sedentary behavior so that interventions can be developed that aim to decrease it.

Defining Sedentary Behavior

Physical activity exists on a continuum with sedentary behavior on one side, vigorous intensity physical activity on the other side, and physical activity of varying intensities in the middle. Researchers have described the differences between exercise physiology and sedentary physiology demonstrating that sedentary behavior is more than just the absence of exercise or a lack of physical activity (Thyfault, 2015). Examples of sedentary behaviors include watching television, using computers, reading, driving, and eating.

According to Tremblay, sedentary behavior can be described using the acronym SITT (Tremblay, 2010). “S” refers to sedentary behavior frequency which represents the number of times that someone is sedentary throughout the day and includes counts such as the number of sedentary bouts that are 30 minutes or longer. For instance, a study examining patterns of sedentary behavior in older adults and middle adults found that almost half of the total sedentary time was accumulated through bouts that were ≥ 30 minutes (Diaz, 2016). The number of bouts of a certain duration, the “S” in this acronym, is therefore important to understand to inform interventions on reducing the amount of sedentary time that individuals engage in. The “I” refers

to interruptions in sitting, such as getting up to get a glass of water while working on the computer. Studies demonstrate that when sedentary behavior is uninterrupted for long periods of time (between 2 hours and 7 days), metabolic factors such as triglyceride levels, insulin sensitivity, and glucose tolerance are negatively impacted (Saunders, 2012). The first “T” represents time (total duration of sitting), and the final “T” refers to the type of sedentary behavior (such as watching television or working on the computer) (Tremblay, 2010).

The mode of sedentary behavior is of particular importance when defining sedentary behavior. A systematic review on adult sedentary behavior concluded that most of the measurements in the literature on sedentary behavior defined sedentary behavior as either television watching or computer use (Rhodes, 2012). This use of a proxy for sedentary behavior indicates that not all forms of sedentary behavior, such as eating, bathing, reading, writing, talking on the phone, and riding in a car, are being taken into consideration in these studies. As a result of using these definitions, there may be an underestimation of the amount of time that individuals spend performing sedentary behaviors. Furthermore, the findings of these studies should be critically examined as the findings may be limited to a type of sedentary behavior and may not hold true for all the other forms of sedentary behavior. For instance, in a systematic review of adult sedentary behavior, Rhodes and colleagues found that there were different associations with health-related outcomes when comparing sitting while using a computer and sitting while watching television (Rhodes, 2012). The review indicated that television watching was associated with being less educated, older, and unemployed, while computer use was associated with being younger and more educated (Rhodes, 2012). Furthermore, although the review found that television watching was associated with lower rates of leisure-time physical activity, it also found that this association was not present for computer use (Rhodes, 2012).

Results from this review further support the idea that sedentary behavior modality is important to consider when examining sedentary behavior, as it is possible that there is a different relationship between forms of sedentary behavior and various health-related outcomes. Furthermore, this study demonstrates that there may be differences within sedentary behavior involving screen-time modalities (e.g., television watching, computer use). Limited research is available to clarify how sedentary behavior modality (e.g., screen-based or non-screen based) relates to health indicators and other outcomes.

The use of screen time (e.g., television and computer usage) versus non-screen time as an indication of sedentary behavior is especially relevant for older adults as this population engages in a substantial amount of screen time. One group of researchers found that the pooled cumulative prevalence of screen time reported by older adults across three countries (U.S., Australia, UK) was approximately 53% reporting more than 4 hours of daily screen time and approximately ~94% reporting more than 2 hours daily (Harvey, 2013). Furthermore, according to the Pew Research Center, about 2/3 of older adults in the U.S. use the internet and around 40% of older adults own smartphones (Anderson, 2017). As the adoption of technology continues to rise in older adults, the amount of screen time and therefore sedentary behavior is also likely to rise.

Demographic & Physical Correlates of Sedentary Behavior in Older Adults

Understanding the predictors of sedentary behavior can broaden our understanding about the risk, maintenance, and prevention of sedentary behaviors. However, research on the determinants of sedentary behavior in older adults is limited. Most studies are cross sectional and do not consider interpersonal or environment factors, such as neighborhood characteristics, or social support. A systematic review of these studies found the correlates or predictors of

sedentary behavior in the majority of these studies to be age, educational attainment, and employment status (Chastin, 2015). Importantly, although these associations were reported, the directionality of the associations between sedentary behavior, age, and employment status were not consistent. Educational attainment findings were consistently associated such that higher education was always associated with less time spent in sedentary behaviors (Chastin, 2015). Other factors such as marital status and sex have been understudied, and therefore, there is little research to support the association between sedentary behavior and these correlates (Chastin, 2015).

There is limited evidence demonstrating the association between physical health and sedentary behavior in older adults. One study found that disabled older adults were more sedentary than other populations with chronic illness or disability (Tudor-Locke, 2013). In the systematic review described above, Chastin and colleagues found that the majority of studies reported an inverse association between measures of health and sedentary time (Chastin, 2015). For instance, researchers have shown that less time spent sedentary is associated with lower body mass index (Bann, 2015) and that higher levels of sedentary behavior are associated with obesity (Chastin, 2015).

Cognitive Correlates of Sedentary Behavior

The relationship between psychological constructs (e.g., cognitive functioning, subjective well-being, mood symptoms) and sedentary behavior is another set of individual-level determinants that is under-studied. A recent review synthesized the results of eight studies of adults, not specifically older adults, suggesting that sedentary behavior is negatively associated with memory, executive functioning, and global cognition (Falck, 2017). However, these findings need to be interpreted with caution due to the lack of high-quality studies, lack of

longitudinal follow up, and the heterogeneous methods of measuring both sedentary behavior and cognition. The authors of this review even comment that the results do not demonstrate whether the relationship is meaningful for global cognition, a handful of cognitive domains, or for a single domain (Falck, 2017). Importantly, even fewer studies consider the relationship between sedentary behavior and cognition in older adults in particular.

Cognitive functioning is of particular importance for older adults as it is directly related to everyday functioning, the ability to live independently, and quality of life. Cognitive changes occur over time as part of the normal aging process. While some domains of cognition, such as general knowledge and some numerical abilities, remain mostly intact, age-related cognitive declines occur in domains that are considered to be ‘fluid’ mental abilities (Deary, 2009). Fluid intelligence, which involves one’s ability to solve new problems, use logic in new situations, and identify patterns, begins to decline progressively during adulthood. Attention and memory have been reported to decline with age and these declines may contribute to deficits in higher order processes such as executive functioning (Gilsky, 2007). These declines in and maintenance of mental abilities are important to understand as they directly relate to an individual’s maintenance of independence.

A few studies have examined the association between sedentary behavior and cognition in older adults, but report mixed results. In older adults in assisted living, sedentary behavior was not associated with scores on a screening measure of overall cognition (Leung, 2017) and another study of older adults found no independent effect of sedentary behavior on attention and psychomotor speed after accounting for the effects of physical activity (Edwards, 2017). No significant correlations between sedentary behavior and cognitive characteristics were found in a sample of community dwelling older adults on a variety of tests including a cognitive screen, a

measure of premorbid intelligence, and measures examining memory, reaction time, and set shifting (Lord, 2011).

Support for a relationship between these constructs include a study of French older adults that found that watching more television (a sedentary behavior) was associated with lower executive functioning scores (Kesse-Guyot, 2012). However, this research was cross-sectional, and there was no association found for verbal memory (Kesse-Guyot, 2012). A study of English community-dwelling older adults, reported a linear inverse association between television viewing and global cognitive function score, while use of the internet was associated with higher cognitive function (Hamer, 2014). Importantly, these sedentary behaviors were self-reported and cognitive functioning was measured as a global cognitive function score which was made up of a memory measure and a measure of executive functioning, as measured by verbal fluency (Hamer, 2014). A study comparing dementia patients with age and sex-matched cognitively healthy older adults found that dementia patients spent more of their waking hours engaging in sedentary behavior (Hartman, 2018).

Taken together, the data examining the relationship between cognition and sedentary behavior in older adults is inconclusive as some studies have found a significant relationship and others have not. Within the small pool of studies that have examined the relationship between sedentary behavior and cognition, there are limitations including the definition, measurement, and operationalization of the two terms that may be related to why no conclusive findings have been drawn. For instance, there is great heterogeneity in the way that cognition is defined and measured (global cognition versus domain-specific measures). In some of the studies, a single domain is considered to be a measure of overall cognition. However, this heterogeneity in definitions of cognition leads to confusion when making generalizations and detracts from our

understanding of the specific ways in which cognition and sedentary behavior may be related.

The direction of influence between the variables is also unclear due to the cross sectional design of the studies. Explanations for a lack of a relationship between sedentary behavior and cognition may include the ability of moderate-to-vigorous physical activity to potentially attenuate the risks associated with sedentary behavior (Edwards, 2017), the limited variability of cognitive scores, the cognitive domains assessed, and the high functioning status of the populations studied.

Potential Mechanisms Linking Cognition & Sedentary Behavior

Previous literature provides plausible explanations for the relationship between sedentary behavior and cognition. On one hand, sedentary behavior may be a cause of cognitive decline, while on the other, cognitive decline likely leads to increased sedentary behavior. The first idea is supported by evidence regarding the close linkage between cardiovascular and metabolic health and brain health. The American Heart Association has set forth guidelines regarding ideal cardiovascular health and researchers have found that people who follow these guidelines more closely have a lower risk of cognitive decline, brain atrophy, and dementia. This suggests that maintaining cardiovascular health protects against forms of vascular brain injury, including Alzheimer's disease (AD) (Pase, 2016).

Many of the risk factors that have been identified for cardiovascular health are either identical or similar to the risk factors identified for metabolic syndrome demonstrating the overlap between metabolic and cardiovascular health (Neergaard, 2017). Sedentary behavior has been shown to have a direct influence on metabolism and vascular health. Previous research has demonstrated that prolonged periods of sedentary time is associated with factors such as glucose and lipid metabolism (Tremblay, 2010). As a result of sedentary behavior, metabolic dysfunction

including increase plasma triglycerides, decreased insulin sensitivity, and decreased has been demonstrated (Tremblay, 2010). Other studies have demonstrated that an extended amount of sedentary behavior can also increase metabolic risk. All of these cardiovascular and metabolic changes are risk factors for cognitive decline and dementia (Kivipelto, 2001; Kloppenborg, 2008; Luchsinger, 2009; Mielke, 2007; Xu, 2007).

On the other hand, sedentary behavior may be a consequence of cognitive decline. As a result of cognitive function declining, individuals may less readily be able to engage in physical activity and, in turn, may engage in more activities related to sedentary behavior. As the brain ages, there are structural changes, such as volume reduction, neuronal atrophy, synapse loss, and neurochemistry changes, as well as functional changes such as in oxygen utilization and glucose metabolism (West, 1996). Although some aspects of cognition and brain function remain stable over time, other aspects such as executive functioning, processing speed, memory, and psychomotor ability are all components of fluid intelligence that may deteriorate over time (Salthouse, 2004). Possible explanations for these changes include the generalized slowing theory (Salthouse, 1996) which suggests that reduced processing speed in older adults leads to slower execution of cognitive operations as well as limitations in the ability to hold information that is needed to perform cognitive tasks and the frontal lobe hypothesis which postulates that functions that are dependent on the frontal lobes decline with age (Moscovitch & Winocur, 1992; West, 1996).

Importantly, cognitive impairment may directly impact the ability to engage in certain modalities of sedentary behavior. A decline in cognitive abilities might be associated with an increase in sedentary behaviors that are passive (e.g., television watching), while a decline in cognitive abilities might be associated with a decrease in sedentary behaviors that are active

(e.g., computer use). This idea is supported by the finding that older adults with memory impairment were less likely to use technology consisting of e-mails, text messaging, and the internet as compared with those without impairment (Gell, 2013). Furthermore, individuals with dementia and mild cognitive impairment perceived the use of everyday technology as more difficult than individuals with no known cognitive impairment (Rosenberg, 2009). These findings provide some evidence that cognitive impairment may be differentially associated with sedentary behavior modality.

Cognitive impairment may also act as a barrier to engagement in physical activity through prohibition of movement and promotion of sedentary behaviors. Evidence has shown that there is age-related decline in measures of executive control, the ability to control behavior, such as initiation in physical activity or any behavior that is likely to decrease one's sedentary behavior time. As a result of cognitive decline, individuals may have weaker self-regulation skills such as poor representation of goals and low levels of attention which may contribute to higher levels of sedentary behavior (Edwards, 2017). Because cognitive control involves executive control, goal maintenance, response selection, and response inhibition, not only may declines in executive function be related to initiation of physical activity, but it may also be related to the sustaining and maintaining of the physical activity. In older adults, studies demonstrated that self-efficacy is related to long-term maintenance of physical activity (McAuley, 2003) as well as overall activity (Resnick, 2001). Another study demonstrated that self-regulation, e.g. more frequently using self-regulatory strategies, was significantly related to greater physical activity participation in older adults (Umstattd, 2008).

Some researchers have considered a bidirectional relationship between health behaviors and executive function. Allan and colleagues present evidence supporting how health behaviors,

focusing primarily on physical activity, play an important role in maintaining executive function and how executive function facilitates participation in health behaviors (Allan, 2016). The authors propose a self-reinforcing and synergistic positive feedback loop between health behaviors and executive function (Allan, 2016) (Figure 3). Although the authors focus primarily on physical activity, it is possible to extend the theory to the relationship between executive function and sedentary behavior.

Purpose

The literature on the relationship between sedentary behavior and cognition in older adults is sparse and inconclusive. More research is needed to determine whether a relationship exists, the possible directionality of the relationship, and the factors that are involved with either moderating or mediating this possible relationship. Better understanding of this relationship has implications for the designs and implementation of interventions that improve healthy aging.

As described above, the SITT model is one way to conceptualize sedentary behavior and is made up of the number of bouts of sedentary behavior, the number of interruptions to sedentary behavior, the total time of sedentary behavior, and type of sedentary behavior. Recent research by Watts and colleagues found that sedentary bout length may hold more importance than total amount of sedentary time per day (Watts, 2016) suggesting that the first T (total time) may not be the most important variable to study. Because the literature on sedentary behavior so frequently lumps together different types of sedentary activity, the present study will break down sedentary behavior into different modalities to further investigate the nature of sedentary behavior. Screen-time variables such as television watching and computer usage will be treated separately as well as non-screen-time variables. To address these gaps in the literature, we will

use objective measures to investigate the relationship between type of sedentary behavior and executive function in older adults.

We focus on the cognitive domain of executive function for several reasons. First, a meta-analysis of prior research indicates that executive function is the cognitive domain most strongly influenced by physical activity (Colcombe, 2003). Although the exact mechanism is unknown, several researchers have investigated the frontal lobe hypothesis of cognitive aging which purports that the frontal lobes are particularly vulnerable to age-related deterioration. As a result, this brain region, and therefore executive function, should be especially sensitive to changes that occur as a result of engaging in physical activity. Following that logic, it is possible that the frontal lobes, and therefore executive functioning, might also be sensitive to changes that occur with sedentary behavior. Although there are differences between sedentary behavior physiology and exercise physiology, there may be some overlap in physiological mechanisms (brain perfusion and glucose regulation) such that executive function may be related to both exercise and sedentary behavior.

Second, executive function includes planning, initiating, and monitoring of complex goal-directed behaviors. Executive function is also directly related to cognitive control, self-regulation, and, motivation which would likely impact the involvement in sedentary behaviors. Individuals with greater executive functioning may have greater cognitive flexibility which would impact the ability to schedule, plan, and execute behaviors that minimize prolonged sedentary behavior (Loprinzi, 2016). Conversely, an individual with limited executive function will be more likely to give into temptations as they have a diminished capacity to self-regulate (Buckley, 2014). Individuals with limited self-regulation capacities have been shown to have

associations with negative healthful behaviors such as low adherence to physical activity and smoking (Buckley, 2014), which might also extend to engagement in sedentary behavior.

To fully understand the relationship between executive function and sedentary behavior, the purposed study will include a population that is cognitively intact and a population that is known to have executive function deficits. Research in the last couple of decades has demonstrated that individuals with AD, including samples of individuals with mild or very mild AD or with a risk of AD, demonstrate impairments on executive functioning (Allain, 2013; Baudic, 2006; Bondi, 2002; Grady, 1988). Therefore, due to the existing literature on executive dysfunction in individuals with AD, the finding that individuals with AD are more sedentary than their cognitively intact counterparts, as well as our access to individuals with AD through the University of Kansas Alzheimer's Disease Center (KU-ADC), older adults with and without AD will be used in the proposed study.

Study Aims

The proposed study will contribute to the body of literature on the relationship between executive functioning and type of sedentary behavior in older adults. The study aims to answer the questions of how type of sedentary behavior (e.g., screen time versus non-screen time) is related to executive function. Specifically, does type of sedentary behavior predict executive function (Aim 1) and/or does executive function predict type of sedentary behavior (Aim 2)? The study also addresses whether the relationship between type of sedentary behavior and executive function differs by AD status. The proposed study addresses the limitations of previous studies by using objective measures (inclinometry) to classify sedentary behavior, subjective measures for context and modality of the aforementioned sedentary behavior, and multiple neuropsychological measures to examine executive functioning.

Hypotheses

Based on previous findings in the literature, we hypothesize a bidirectional relationship between executive functioning and type of sedentary behavior. We also hypothesize that greater executive functioning will be negatively associated with overall time spent in sedentary behavior for both older adults with and without AD. Furthermore, based on previous research regarding differences between television and computer use, we hypothesize that there will be differences in the relationship between executive function and types of screen time such that sedentary time involving television watching will be negatively associated with executive function while sedentary time involving computer use will be positively associated with executive function. Due to insufficient previous research on the differential effects of different types of sedentary behavior, no specific hypotheses regarding the other specific types of sedentary behavior and their relationship to executive function were made. However, due to the biological mechanisms described above, there was reason to hypothesize that there would be a relationship between executive function and other forms of sedentary behavior.

Methods

Participants

Participants were 100 community dwelling older adults, aged 60 to 92, with and without mild AD (N = 47 mild AD, N = 53 controls). Demographic characteristics are presented in Table 1. Participants were recruited from the KU-ADC Clinical Cohort, a large registry of well characterized AD patients and older adult controls without cognitive impairment who have undergone full physical and neurological examination and review of medical history before being recruited into the study. Recruitment was conducted by contacting existing registry participants by mail and telephone to invite them to participate.

A comprehensive clinical research evaluation and review of medical records were performed by clinicians to determine severity of AD. Participants with mild AD had clinical dementia rating (CDR) scale scores of 0.5 (very mild) or 1 (mild). Older adult control participants had CDR scores of 0 (indicating no dementia). Further description of the recruitment and diagnosis of this population can be found elsewhere (Watts, 2016). To be included in the study, participants with AD had to have a study partner who accompanied them on their study visits. Other inclusion criteria were a minimum age of 60 years and community dwelling. Individuals were excluded if they were confined to a bed or wheelchair or if they had inadequate visual or auditory capacity to complete study procedures. The clinical cohort excludes individuals with active (< 2 years) ischemic heart disease (myocardial infarction or symptoms of coronary artery disease such as angina) or insulin dependent diabetes mellitus. Individuals with well controlled, non-insulin dependent diabetes were included.

Procedures

The study was approved by the Human Subjects Committee at the University of Kansas Medical Center and informed consent was provided by the participant and/or the participants legal representative. At a baseline visit, participants completed questionnaires and were educated on the use of the activity and postural monitoring devices (detailed below) and activity monitor wear logs. Participants wore two separate monitors simultaneously, though only the data from the postural monitor will be described in the present study.

We chose the activPAL™ based on previous literature indicating that the activPAL™ (Pal Technologies, Glasgow, Scotland) assessed sedentary behavior more accurately than the ActiGraph GT3X (Kim, 2015). The activPAL™ is an accelerometer-based posture and activity assessment device that quantifies postural allocation. Thigh placement has been demonstrated to

more accurately estimate sedentary posture than other body placements including wrist and waist (Byrom, 2016). An activPAL™ worn on the thigh has been validated for accurate detection of assessment of sitting and changes in sitting vs. standing postures (Kozey-Keadle, 2011). The activPAL™ monitor collects data in 15 second epochs.

Study staff attached the activPAL™ postural monitors to participants' dominant thigh according to the manufacturer's recommended waterproofing protocol to allow wear during showering or bathing. Participants were instructed to wear the units 24 hours a day for 7 days or until they returned to the clinic for a follow up visit. Participants were asked to fill out logs to monitor daily activities, any removal of the devices and reasons for removal, and bedtime and waking time. At a follow up visit, participants returned the monitors, reviewed the activity logs with study staff, filled out questionnaires, conducted cardiorespiratory (VO₂max) testing, and were compensated for their participation.

Measures

Measurement of Sedentary Behavior

Monitor Wear Time Validation. We used participant wear logs to identify and exclude night time sleep from the analyses. Day time napping was excluded as sedentary behavior. Thus, estimates of sedentary time include only waking hours. Data were included in analyses if they met the following valid wear time criteria: 1) a valid day of wear is ≥ 10 hours, 2) minimum of 4 days of valid wear, 3) at least 1 weekend day (Kozey-Keadle, 2011). We excluded any data collection days where participants reported removing the device, other than during sleep time and while bathing. Data from the inclinometers were downloaded and checked for outliers and out of range values. After the data was wear time validated, sedentary behavior was derived using proprietary algorithms (Intelligent Activity Classification™) that, based on thigh position

and acceleration, determine body posture and transitions from the postures to stepping to calculate sedentary behavior (Edwards, 2017).

ActivPAL™ Data. Data extracted from the monitors included proportion of 30-minute blocks in which the person was sedentary. This information was transformed into percentage of time sedentary (out of the 30 minutes) and number of sedentary minutes within the 30-minute epoch. A 30-minute period of behavior was considered to be a sedentary period of 30 minutes if the proportion of sedentary behavior equated to ≥ 20 minutes. As there are no known papers in the literature that report exact measurements for a threshold or proportion of 30-minute epochs that are considered to be sedentary using activPAL™, this cutoff was chosen as ≥ 20 minutes represents 66.66% or more time spent sedentary during the block. This cut-off means that the vast majority of time during that period was spent in sedentary behavior.

Daily Activity Logs. While the use of objective postural monitoring devices minimizes the likelihood of measurement error, it does not provide context for the specific behaviors being observed. Because different types of sedentary behavior are associated with different outcomes, participants were asked to fill out daily activity logs. Individuals were asked to write down their activities in half hour intervals throughout the waking hours of the day indicating the activity (e.g., watching television, eating breakfast, performing yardwork, emptying the dishwasher) along with the position (lying down, sitting, standing, or moving), the perceived intensity (light, moderate, vigorous), and the location (home, store, etc.). Few studies report use of diary data and activPAL™ data together (Edwards, 2017).

Sedentary Behavior Categories. Based on self- or study partner-reported activity logs, sedentary behavior was further broken down into type of sedentary behavior (screen based vs. non-screen based). Based off of the reported activity or activities, sedentary behavior was coded

into different categories. The screen based categories included television watching, computer use, multiple screen use (a combination of different mediums of screen time either simultaneously or sequentially – e.g., using both a computer and a television within the 30-minute period), and other screen time (e.g., going to the movies). A category called non-screen time was created which included all the activities that didn't involve screens (e.g., reading, eating/meal prep, driving). A mixed category for screen and non-screen activities was created which included periods in which someone engaged in both an activity that was screen related and an activity that was not screen related (e.g., eating lunch and then watching television or eating lunch while watching television). Lastly, a category for unknown sedentary time was created. This category included periods that were known to be sedentary (based off of activPAL™ data) but was either missing a corresponding activity from the daily activity log or was related to a corresponding activity that was difficult to categorize (e.g., sitting activities at an adult day center).

Total number of 30-minute blocks of each category were calculated. Total amount of sedentary time per person was calculated by summing the total number of sedentary blocks per person. Using the overall total of sedentary periods per person, the proportion of time spent in each sedentary activity was calculated for each individual.

Sedentary Behavior Variable Creation. In the present study, objective data was first used to designate 30-minute periods of sedentary behavior. This objective period was then compared to its corresponding 30-minute time period in the diary data to determine the type (or types) of activity in which the individual engaged. The sedentary behavior period was then categorized into one of seven categories (i.e., television, computer, multiple screens, other screen, non-screen, mixed screen and non-screen, and unknown).

Executive Function

Neuropsychological tests were administered to participants as part of the annual clinical cohort visits at the KU-ADC. We included the neuropsychological data that was collected nearest in time to wearing the monitors and completing the activity logs. The difference between neuropsychological data administration and activPALTM data collection ranged from <1 month to ~32 months with the average length of time difference being 33.63 days (SD = 167.89). All participants were administered a standardized clinical battery which included tasks of executive functioning, memory, attention, language, and processing speed. For the purposes of this study as described above, only tests of executive function will be included in the analyses. Tests of executive function to be analyzed include: Stroop Interference, Trail Making Test B, Digit Symbol Substitution Test, and category fluency.

Stroop Interference. The Stroop test, (Golden, 1978), is used to measure cognitive flexibility, resistance to interference from outside stimuli, and the ability to suppress a verbal response. Individuals are asked to read three different words as quickly as possible. Two of them are “congruous” while the third one, the interference task, is incongruent. On this task, individuals must name as quickly as possible the color ink (which is discordant with the color word) in which the words are printed rather than reading the word. Higher scores indicate better performance.

Trail Making Test (TMT). The TMT (Army Individual Test Battery, 1944), is a paper and pencil test of visual search, scanning, speed of processing, mental flexibility, and executive function that consists of two parts. The first part, TMT-A, requires individuals to draw lines that connect numbers in sequential order. The second part, TMT-B, has the person alternate from numbers to letters in ascending order (1, A, 2, B, 3, C, etc.). TMT-B has been shown to be more

strongly associated with executive function compared to TMT-A. On this subtest, the score is the total number of seconds that it takes to complete the task. Higher scores indicate slower performance. The total possible score is 300 seconds at which time the test is discontinued. During analysis procedures, these scores were reverse coded to allow them to be interpreted in the same direction as the other tests, that is, a higher score is interpreted to mean better performance.

Digit Symbol Substitution Test (DSST). The DSST, a subtest on the Wechsler Adult Intelligence Scale- Revised (WAIS-R), is a paper and pencil test of psychomotor performance (Wechsler, 1981). Individuals are given a key grid of numbers and matching symbols and are given 90 seconds to fill as many empty boxes as possible with the symbol matching each number. This task requires response speed, sustained attention, visual spatial skills, and set shifting. The number of correctly completed squares is the total score. Higher scores indicate better performance.

Category Fluency. Individuals are given 60 seconds to generate as many words as possible, in English, belonging to a particular category. Individuals were asked to name vegetables and animals. Higher scores indicate better performance. The sum of the two categories was used as the total score.

Covariates

Age at inclinometer visit, sex, race, education level, body mass index, and dementia status (i.e., with or without AD) were included in analyses as covariates. Age and education level were included as covariates because of the review article which found that most studies found a relationship between these variables and sedentary behavior (Chastin, 2015). A study by Bellettiere and colleagues looking at a retirement community, found that older men were more

sedentary than older women (Bellettiere, 2015). Although the reason is unknown, the authors speculate about activities that there may be differences in the activities that men perform versus women (e.g., housework and chores). Therefore, because there may be a difference in the type of sedentary behavior that men and female engage in, sex was a covariate. Body mass index (BMI), was included as a covariate because BMI, specifically overweight and obese classifications, have been associated with sedentary behavior in middle-aged and older adults (Diaz, 2016).

Although we have very little diversity in race in our sample, race was included as a covariate as there is evidence that race has a direct effect on late-life cognitive functioning (Zsembik, 2001) and that in adults, disparities in executive functioning composite scores between races exist (Zahodne, 2016). Dementia status, (i.e., whether someone has dementia or not), was used as a covariate because of the known association between dementia and executive function deficits. An interaction term between AD status and proportion of screen time was included as a covariate for the first study aim while an interaction term between AD status and EF score was included as a covariate for the analyses related to the second aim.

Statistical Analysis

Data were processed, wear time validated, and cleaned, using activPAL3TM software, and analyzed using a combination of descriptive and inferential statistics using IBM SPSS Statistics 23 (SPSS Inc., Chicago, IL, USA). Descriptive analysis was calculated to summarize patterns of sedentary behavior across the 7 days of data collection, Calculations include the total number of 30-minute sedentary blocks and the total number of 30-minute sedentary blocks spent in screen and non-screen time activities.

To parsimoniously characterize executive function, we used confirmatory factor analysis of relevant tests. Factor scores were estimated in previous research using cognitive data at the

KU-ADC. This approach improves measurement accuracy by using multiple measures assessing the same cognitive domain. Factor analytic techniques aggregate common variance across multiple subtests in a weighted linear combination and attenuate error idiosyncratic to the individual tests. Scores were standardized to the mean of the non-impaired control group. Thus, scores can be interpreted relative to the non-impaired group. As a result, some individuals have negative scores.

Correlation and linear regression were used to determine the relationship between type of sedentary behavior (screen time vs. non-screen time) and executive function. To address aim 1, to determine whether types of sedentary behavior differentially predict executive functioning, stepwise linear regression was conducted adjusting for the covariates described above. Specifically, the types of sedentary behavior included the proportion of time spent engaging in television, computer, multiple screens, other forms of screen time, non-screen time, mixed screen & non-screen time, and unknown sedentary time. The dependent variable was executive function factor score. To address aim 2, to determine whether executive functioning predicts types of sedentary behaviors, 8 stepwise linear regression models were conducted adjusting for the aforementioned covariates. In these models, the independent variable was executive functioning score while the dependent variables were proportion of time spent in each type of sedentary behavior. We used the False Discovery Rate procedure to adjust for possible inflation of Type 1 error associated with multiple testing (Benjamini & Hochberg, 1995).

Results

Characteristics of the Sample

Demographic information is presented in Table 1. Of the 100 participants that were enrolled in the study, there were 80 individuals with valid activPALTM data (N = 44 cognitively

normal older adults, $N = 36$ individuals with AD). Nine participants were not given an activPALTM (7 due to being part of a pilot study, 1 due to contraindications with a scheduled MRI scan, and 1 due to an adhesive allergy). Of the 91 individuals given an activPALTM monitor, data from 11 participants could not be used. Reasons for this include participant withdrawal (1), monitor malfunctions (6), fewer than 4 valid days of data recorded (1), no valid weekend day of wear (1), erroneous daily activity logs (1), and missing inclinometer data (1).

Of the 80 individuals with valid activPALTM data, one individual was missing BMI information. Mean substitution of a sex and dementia status matched sample was used to compute this value for the one individual missing data.

Independent samples t-tests were run to determine whether there were significant differences between the groups with and without valid activPALTM data. There were no statistically significant differences between the two groups in terms of AD status, sex, age, years of education, and BMI. Descriptive statistics relating to executive function factor scores and inclinometer-derived sedentary behavior can be found in Tables 2 and 3 respectively.

Executive Function and Sedentary Behavior Descriptive Statistics

Executive function factor scores by AD status are presented in Table 2. Inclinometer-derived sedentary behavior descriptive statistics are presented in Table 3. There were no statistically significant differences between individuals with and without AD regarding the total number of 30 minute blocks of sedentary time, $t(78) = -1.088, p = .280$. There was, however, a statistically significant difference between the total number of 30 minute sedentary blocks spent watching television between these groups, $t(60.609) = -3.975, p < .001$ such that individuals with AD had more periods of television use than individuals without AD. There were no other statistically significant differences between AD status and types of sedentary behavior.

Correlations

Across the entire sample, there was no correlation between executive function scores and the total number of 30-minute blocks of sedentary time, $r = -.069$, $p = .546$. There was a positive correlation between executive function scores and the proportion of sedentary time spent using a computer, $r = .230$, $p = .040$. There was a negative correlation between executive function scores and the proportion of sedentary time spent watching television, $r = -.429$, $p < .001$.

Study Aim 1 (Directionality – Outcome: Executive Function)

A two stage stepwise linear regression was used to determine whether types of sedentary behaviors predicted executive function scores after controlling for demographic covariates (Table 4). Age, sex, education, race, BMI, dementia status, and the interaction term (ADstatus*ScreenTimeProportion) were entered in step one of the regression to control for demographic variables. The sedentary behavior variables were entered in step two. These variables included: proportion of time spent watching television, using the computer, using multiple screens (either sequentially or simultaneously), using another type of screen, using a combination of both screen and non-screen activities (either sequentially or simultaneously), engaging in non-screen activities, and unknown sedentary behaviors. Proportion of sedentary time spent engaging in non-screen activities was excluded so as a reference category. The results from this regression are presented in Table 4. The results revealed that at step one, sex, education, and dementia status contributed significantly to the regression model $F(7,72) = 12.306$, $p < .001$. The entire model accounted for 54.5% of the variation in executive function scores. Introducing the sedentary behavior variables explained an additional 6.7% of the

variation in executive function scores and made sex no longer a significant predictor. However, the change in R^2 was not significant $F^{\Delta}(6, 66) = 1.883, p = .097$.

The overall model was predictive of executive function scores accounting for 61.1% of the variation $F(13,66) = 7.174, p < .001$. Education, dementia status, and the proportion of time spent engaging in mixed screen & non-screen activities were significant predictors of the overall model.

Study Aim 2 (Directionality – Outcome: Sedentary Behavior Modality)

Eight stepwise linear regressions were used to determine whether executive functioning scores predicted type of sedentary behaviors after controlling for demographic covariates. Age, sex, education, race, BMI, dementia status, and the interaction term (ADstatus*EF) were entered in step one. Executive function scores were entered in step two. The dependent variables for each of the 8 models were proportion of sedentary time spent: watching television, using the computer, using a different form of screen time, using multiple forms of screen time (either sequentially or simultaneously), engaging in overall screen time, engaging in non-screen time, engaging in mixed screen and non-screen time, and engaging in unknown activities. The results from the regressions can be found in Table 5. There were no significant overall models for computer usage, multiple screens time, other screen time, non-screen time, and unknown screen time. There were, however, significant models for television watching, overall screen time, and mixed screen and non-screen time. The Benjamini-Hochberg false discovery rate was set to .25. The procedure was run using the predictors from Model 2 across the 8 models (for a total of 64 variables). The only individual predictor that remained significant after this test was executive function score as a predictor for proportion of time spent performing mixed screen and non-screen sedentary behavior.

Proportion of Television Watching

For television watching, the results revealed that at step one, years of education and dementia status contributed significantly to the regression model, $F(7, 72) = 3.762, p = .002$. The entire model accounted for 26.8% of the variation in the proportion of time spent watching television. Introducing executive function scores explained an additional 3.2% although this change in R^2 was not significant $F^\Delta(1, 71) = 3.264, p = .075$. The overall model was predictive of television watching and accounted for 30.0% of the variation $F(8, 71) = 3.803, p = .001$. In the overall model, there were no significant individual predictors.

Proportion of Overall Screen Time

We found a similar pattern for overall proportion of screen time (made up of television watching, computer use, multiple screens time, and other screen time). For overall screen time, the results revealed that at step one, years of education and dementia status contributed significantly to the regression model, $F(7, 72) = 2.598, p = .019$. The entire model accounted for 20.2% of the variation in the proportion of time spent using screens. Introducing executive function scores explained an additional 1.1% although this change in R^2 was not significant $F^\Delta(1, 71) = .999, p = .321$. The overall model was predictive of screen time and accounted for 21.3% of the variation $F(8, 71) = 2.398, p = .024$. In the overall model, there were no significant individual predictors.

Proportion of Mixed Screen and Non-Screen Sedentary Time

For the proportion of time that an individual was sedentary and engaging in both screen and non-screen activities, the regression did not reveal a significant model in step one, but revealed a significant model in step 2, $F(8, 71) = 2.896, p = .008$. Introducing executive function scores explained an additional 10.2% and this change in R^2 was significant $F^\Delta(1, 71) = 9.611, p$

= .003. The overall model accounted for 24.6% in the variation of proportion spent engaging in both screen and non-screen activities with executive function scores and the interaction between AD status and EF score being significant predictors. However, after controlling for the false discovery rate, executive function scores were the only significant predictor.

Discussion

The purpose of the current study was to explore the potential bi-directional relationship between sedentary behavior and executive function. That is, the impact of different types of sedentary behavior on executive function performance and the impact of executive function on different types of sedentary behavior. Specifically, we were interested in sedentary time spent engaged in screen-based activities vs. non-screen-based activities.

The hypothesis that there would be a bi-directional relationship between type of sedentary behavior and executive function was partially supported by the results from Aim 1 and Aim 2. Partial support for this hypothesis came from the finding that only one type of sedentary behavior predicted executive function scores and that the same type of sedentary behavior was predicted by executive function scores.

We also hypothesized that individuals with greater executive functioning would spend less time in overall sedentary behaviors. This hypothesis was not supported by the analyses. Lastly, we hypothesized that there would be a differential relationship between executive function scores and sedentary time spent engaging in television watching and computer use. This hypothesis was supported by the finding that sedentary time spent television watching was associated with lower executive function scores while sedentary time spent using the computer was associated with higher executive function scores.

The first aim of the study assessed whether specific types of sedentary behavior were predictive of executive function performance after controlling for demographic variables. We found that the vast majority of the variance in executive function scores was explained by dementia status, education, and sex. It was unsurprising that non-impaired cognitive status was associated with better executive function as this finding aligns with previous research regarding the strength and weaknesses of those with cognitive impairment related to AD. It was also unsurprising that education level was predictive of executive function as normative data for measures of executive function often take into account both age and education. For instance, normative data for the TMT demonstrate that performance on this task decreases with increasing age and lower levels of education (Tombaugh, 2004) and other studies have shown that education is positively related to Stroop test performance in normal aging individuals (van Boxtel, 2001). Because research has shown that education level impacts executive function, normative data takes education into account.

In the first stage of the model, sex was also predictive of executive function scores such that men had lower scores compared with females. This finding may be consistent with recent research describing how there may be individual factors that show a tendency towards a sex bias in executive function (Grissom, 2018). This review found increased impulsive action in males, reduced reaction time in males, and improved working memory in females (Grissom, 2018). However, other studies have demonstrated mixed findings and even the authors from the current review explain that the differences found may relate to executive function strategy more so than executive function ability (Grissom, 2018).

The inclusion of types of sedentary behavior on top of the demographic variables, added a small proportion of explanatory power in executive function scores to the overall model,

although the addition was not significant. In the overall model, education, dementia status, and the proportion of sedentary time spent engaging in mixed screen and non-screen activities each accounted for significant unique variances in the prediction of executive function scores. It is unsurprising that education and dementia status remained significant predictors after the addition of sedentary behavior variables.

Only one type of sedentary behavior uniquely predicted executive function. Time spent engaging in both screen and non-screen activities simultaneously accounted for a small but significant proportion of the variance in executive function such that a higher proportion of mixed screen and non-screen time was associated with better executive functioning performance. This type of sedentary behavior may be indicative of cognitively high functioning individuals.

Regarding sedentary behavior, only the proportion of time spent watching television and overall screen time, were predicted by predicted by demographic variables. It is likely that the time spent watching television is driving the results related to the overall use of any screen time because the other forms of screen time were not significant predictors, and because television time was the most frequent type of screen used. This is consistent with research that has shown that older adults are the age group that spend the most time watching television (Gardener, 2014). Higher education and normal cognitive status predicted lower proportion of time spent watching television. This finding is supported by data from the American Time Use Survey showing that for adults 25 years and older, time spent watching television decreases as education increases (Bureau of Labor Statistics, 2018). As compared to non-impaired individuals, those with AD had higher levels of television watching. This finding might be explained by the amount of time that individuals with AD have, as well as diminished capability to engage in activities that they had previously engaged in. Furthermore, watching television is a passive activity while

other forms of screen use may be considered to be more active. Research has shown that watching less television is associated with decreased odds of having mild cognitive impairment (an early form of AD) while reading books, playing games, and other engaging cognitive activities were significantly associated with decreased odds of having mild cognitive impairment (Geda, 2011).

Importantly, when executive function scores were added to the model, there were no longer individual predictors of the proportion of time spent sedentary while watching television. This finding may be explained by the collinearity between AD and executive function scores in this model such that these predictors could not independently predict the proportion of time spent sedentary while watching television. Further analyses were run to test the hypothesis that both AD and executive function scores contribute independently to the time that is spent watching television but may not be predictive independently when combined in the same regression model. A separate model that excluded AD status but included demographic variables (i.e., race, sex, education, BMI, and age) and executive function scores was run. This model was also predictive of the proportion of time spent watching television (explaining 25.1% in the variance) with executive function being predictive of television watching such that lower executive function scores were associated with more television time. The results of these additional analyses indicate that those with AD spent more time watching television and those with lower executive function spent more time watching television. Because someone with AD is likely to have impairments in executive function, it makes sense that when executive function and AD are added into the same model, while overall time spent watching television is significant, there are no individual predictive factors.

This finding also suggests that while a number of variables added together predict sedentary time spent television watching in older adults with and without AD, no one single factor is predictive of this behavior and that other, unmeasured, factors may be stronger predictors than the ones used in the current study. For instance, a cross-sectional study of older adults in Belgium found that higher levels of television watching was associated with those that were functionally limited, less education, widowed, and (semi-) urban dwelling (Cauwenberg, 2014) while a longitudinal study of older adults found that increases in television watching were associated with lower socioeconomic status, depressive symptoms, higher BMI, lower levels of physical activity, and being a smoker (Gardner, 2014). It is possible there are other variables that explain the relationship between executive function and the proportion of sedentary time spent watching television that were not considered in the current study such as employment status and type of employment. Other possible mechanisms may include mood, sleep, presence of chronic health conditions, social isolation and support, and pain. More research is needed to further elucidate what contributes to the proportion of time that an older adult watches television and engages in any type of screen use.

Furthermore, the proportion of time spent engaging in both screen and non-screen activities was predicted by executive function scores such that higher executive function scores were predictive of more time spent in sedentary behaviors periods made up of a mix of screen and non-screen time. Taken together, the findings from the two study aims suggest a positive association between executive function and sedentary time such that higher levels of executive function were associated with a larger amount of time spent engaging in sedentary behavior marked by both screen and non-screen time during the same 30-minute period.

Based on the percent of variance that was explained in each of the models, we conclude that executive function performance contributed more to sedentary behavior spent engaging in both screen and non-screen activities during a 30-minute block of time than sedentary behavior spent engaging in both screen and non-screen activities contributed to executive function performance. This suggests that cognitive abilities contribute to the engagement in mixed screen and non-screen sedentary behavior more so than the engagement in mixed screen and non-screen sedentary time contributes to cognitive abilities. This finding also suggests that individuals with poorer executive function may not be able to engage as readily in sedentary time that is made up of both screen and non-screen activities.

The positive relationship between executive function and sedentary time that is composed of both screen and non-screen time might be explained by the components of executive function, namely, dual-task performance, and multitasking. Research has shown that executive function is directly implicated in the ability to engage in dual-task performance, requiring concurrent and simultaneous task processing and motor responses, and task switching, multitasking with sequentially processed component tasks (Strobach, 2018). Individuals with poorer levels of executive function are less able to task switch and engage in multiple activities at once.

The relationship between executive function and sedentary time involving mixed screen and non-screen time might also be explained by individuals breaking up their sedentary time more frequently. Although not directly tested in the current study, it is possible that the individuals who switched tasks during the 30-minute sedentary period had more transitions between standing and sitting. Research has shown that there is a positive association between breaks in sedentary time and physical function in older adults (Sardinha, 2014). A review by Benatti and colleagues concluded that experimental studies provide evidence on the positive

impact of breaking up prolonged sitting time on metabolic outcomes (Benatti, 2015). There may be also be cognitive contributions or consequences related to the number of breaks in sedentary time, however a pilot study found no relationship between these constructs in a small sample of overweight adults (Wennberg, 2016).

The results from this study indicate that no other type of sedentary behavior was a unique contributor to executive function performance and that executive function scores were not a unique contributor to any other types of sedentary behavior. Previous research has found positive associations between computer use and executive function scores in studies of adults (Tun, 2010). In the Tun study, sedentary time was not directly measured. Computer use, which is assumed to be sedentary time, was measured via self-report and executive function was measured via a single test over the phone. Perhaps our results differ due to methodological differences including the measurement of sedentary behavior, the measurement of executive function, and the population being studied as executive function declines with age and may present differently in studies of adults versus older adults. Furthermore, in the current study, shorter periods of sedentary time using the computer (<20 minutes) were not necessarily captured in the data. Perhaps the sedentary factor impacts the relationship between computer use and executive function and explains why there was no relationship between sedentary time using a computer and executive function performance in the current study.

There are several potential explanations for our findings that executive function performance and types of sedentary behavior including computer use, multiple screen use either sequentially or simultaneously, other screen use, and non-screen time were not related. For one, some of these types of sedentary behavior, such as computer use, were not engaged in often by the older adults in this sample. Additionally, for multiple screen use, which may have included

blocks of time where screens are used sequentially, there may be something different about switching from screen to screen rather than from switching from screen to non-screen. Perhaps regular physical activity has a protective effect on executive functioning thus making the effects of sedentary behavior or the relationship between these two constructs unnoticeable. Recent research has looked into the combined effects of time spent in physical activity, sedentary behavior, and sleep and have found that the distribution of these three were significantly associated with health outcomes such as BMI, waist circumference, triglycerides, and blood pressure (Chastin, 2015). Other studies have shown that replacing sedentary behavior with any form of physical activity (light, moderate, or vigorous intensity) in older adults has positive implications for health outcomes. Relatedly, a study of older adult men showed associations between higher daily step counts, minutes spent in light physical activity or moderate-to-vigorous physical activity, lower sedentary time, and a lower risk of all-cause mortality (Jefferis, 2018). Future studies should consider taking physical activity levels into account, as the effects of physical activity and sedentary behavior each have unique contributions to health outcomes.

An alternative explanation might be that the types of sedentary behavior we studied require less executive function ability than does sedentary behavior that involves both screen and non-screen activities. For instance, using the computer or doing something not screen related (e.g., grooming, household chores, and eating) is likely to require fewer executive function abilities such as cognitive flexibility or inhibitory control than engaging in dual-tasks or multitasking. There may be differential relationships between types of sedentary behavior and other areas of cognition that we did not include in the present study. Future studies should consider other domains of cognition such as overall cognition, memory, or processing speed.

The current study was the first to assess the bi-directionality of the association between executive function and screen-based versus non-screen based types of sedentary behavior in older adults with and without AD. The study adds to the existing literature by examining the possible bi-directional relationship of these constructs. This study is also important methodologically because of its use of both objective and subjective measures to quantify sedentary time as well as its measurement of executive function through a factor score. The results of this study demonstrate that there are differential relationships between types of sedentary behavior, executive function, and demographic variables. The study shows a positive association between executive function performance and sedentary behavior involving both screen and non-screen time. The results demonstrate a significant negative relationship between both dementia status and executive function performance with overall screen time such that having AD, and having lower executive function performance are associated with a higher likelihood of spending time watching television. No other associations between executive function performance and sedentary behavior involving other types of screen use and non-screen use were found.

Taken together, these findings suggest differential relationships of correlates of screen-time sedentary behaviors and non-screen sedentary behaviors. Therefore, interventions aimed at decreasing sedentary behavior need to be specific about the type of sedentary behavior that they wish to target as the findings from this study suggest that not all forms of sedentary behavior are negatively associated with cognition. Researchers and clinicians may want to target a decrease in sedentary behaviors that are more passive (e.g., television watching) rather than sedentary behaviors that are more mentally active (e.g., computer use). Television watching may be a particular point of intervention as this activity was the screen-based activity that individuals

engaged in most. Findings from this study support the notion that interventions to decrease sedentary behavior should consider decreasing bout duration. For individuals with executive function deficits, it may be beneficial to provide reminders and motivators related to decreasing time spent sitting.

Interventions aimed at decreasing sedentary behavior can largely disregard the role that executive function may have on sedentary behavior and instead may choose to focus on other points of intervention (e.g., home environment). Findings from the study also suggest that interventions that aim to improve executive function abilities may have implications for sedentary behavior such that preservation of executive function may mean that individuals are able to engage in activities that involve multiple mediums. More research is needed to determine how the preservation of this ability might be advantageous.

Further studies should use longitudinal analysis and path modeling to better understand the potential mediators and moderators of the relationship between types of sedentary behavior and executive function. A better understanding of the causal direction of these constructs may help inform interventions or points of intervention. Future studies should also examine engagement in sedentary behavior consisting of multiple non-screen activities as compared to the engagement in sedentary behavior consisting of both screen and non-screen based activities to further elucidate the current findings.

Results from the current study also have implications for the measurement of sedentary behavior. Due to the differential associations of types of sedentary behavior and executive function, it is important that researchers look at sedentary behavior modality instead of combining sedentary behavior into one category. Researchers should also attempt to measure length of sedentary bouts rather than overall total sitting time. The notion of using a 30 minute

cut-point for prolonged sedentary behavior is based on research showing that >30 minute bouts of sedentary behavior have detrimental cardio-metabolic effects (Peddie, 2013). Further support for this cut-point comes from a study looking at sedentary behavior in children and adolescents that found that 30 minute bouts fit better with cardio-metabolic risk factors than shorter bout periods i.e., 5 or 10 minutes) (Carson, 2011). However, objective sedentary measures have shown that individuals accumulate sedentary time in bouts that are less than 30 minutes. Data from the Women's Health Study showed that almost 70% of sedentary time that older women spent was accumulated in bouts less than 30 minutes (Shiroma, 2013). Therefore, subjective measures might consider characterizing bouts of sedentary behavior that are less than 30 minutes. Detailing smaller portions of time will help gaining a deeper understanding of sedentary behavior and can be used to help researchers develop more specific, more accurate, and more personalized interventions.

Limitations

There were a number of methodological factors that limit the conclusions drawn by this study. First, the study was cross-sectional in nature and, as a result, no conclusions can be made about causality. However, because both directions were tested, it is possible to infer that executive function contributes a greater proportion of variance explained to the proportion of sedentary time spent engaging in sedentary behavior made up of screen and non-screen activities than the reverse. Another limitation is that the sample consisted primarily of highly educated white individuals, which is not generalizable to the larger population. Future research should aim to include a broad set of individuals with a range of demographic variables including race, ethnicity, age, and education.

A further limitation is the way in which sedentary behavior was calculated. To compare to the activity logs, sedentary behavior was chunked into thirty minute epochs based on whether an individual was sedentary for ≥ 20 minutes of that period. However, in reality, individuals were not necessarily sedentary for the entire 30-minute epoch (e.g., many individuals used computers for less than 20 minutes per bout). Additionally, 20 minutes was an arbitrary cutoff such that different results may have been found if the cut-off was ≥ 25 minutes. Furthermore, the use of self-reported activities made it difficult to accurately classify exactly what activity people were engaged in. As the focus of the current study was to focus on screen based sedentary activities, the categories for screen based activities were more precise than the category for non-screen activities. For instance, the non-screen activity category includes blocks of time where someone was engaged in a single sedentary non-screen activity (e.g., driving) but also blocks of time where someone engaged in multiple sedentary non-screen activities (e.g., grooming, eating, and reading). Relatedly, it was sometimes unclear whether the individual was engaging in tasks simultaneously or sequentially. Future studies should consider using other ways of categorizing and quantifying types of sedentary behavior to best understand the relationship between the constructs. A final limitation of the current study is that sedentary behavior is measured over a one-week period of time which might not necessarily reflect the habitual level of sedentary behavior over a longer period of time. The Hawthorne effect, or the finding that individuals modify their behavior in response to their awareness of being observed, might be a limitation in this study. Therefore, capturing sedentary behavior over a longer period of time may reduce the likelihood that the Hawthorne effect may have.

Conclusion

Interventions to reduce sedentary behavior in older adults need to take into account the form of sedentary behavior that it is targeting as types of sedentary behavior have unique correlates associated with it. Television watching, considered a passive form of sedentary behavior, was associated with AD status and lower education. A form of sedentary behavior involving a mixture of screen and non-screen time was positively associated with executive function performance suggesting that mentally-active forms of sedentary behaviors may be beneficial, or at least not detrimental, to older adults. The implications from this study suggest that health outcomes of sedentary behavior need to consider modality of sedentary behavior. Individuals should be educated on the differences between types of sedentary behavior and outcome and healthy screen viewing habits, such as setting limits on television time should be encouraged.

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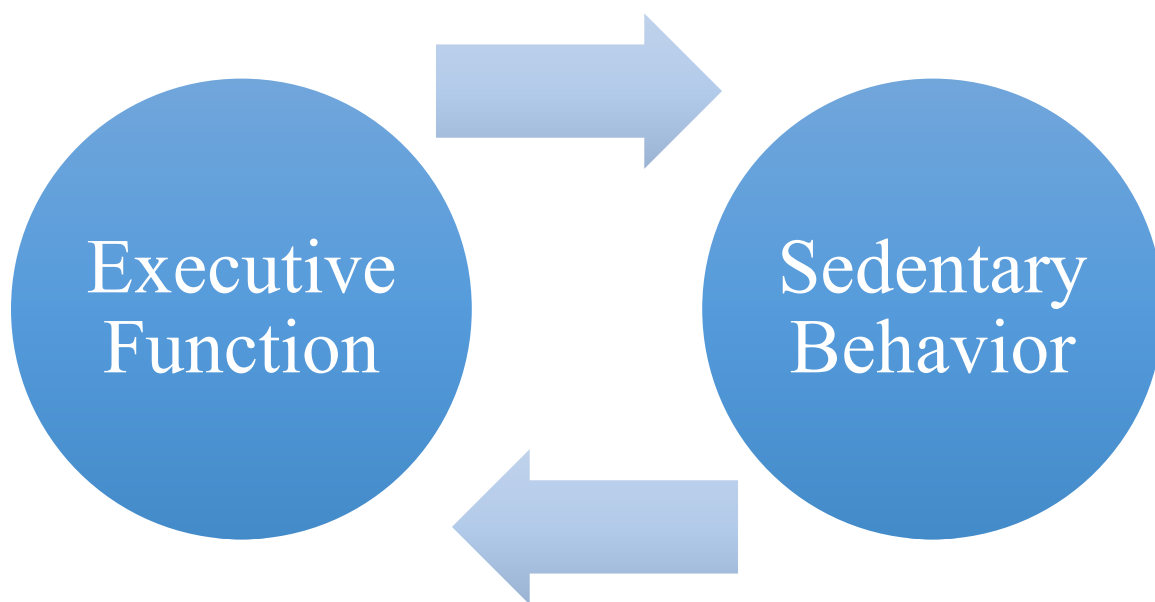


Figure 1. The relationship between executive function and sedentary behavior in older adults is unclear.

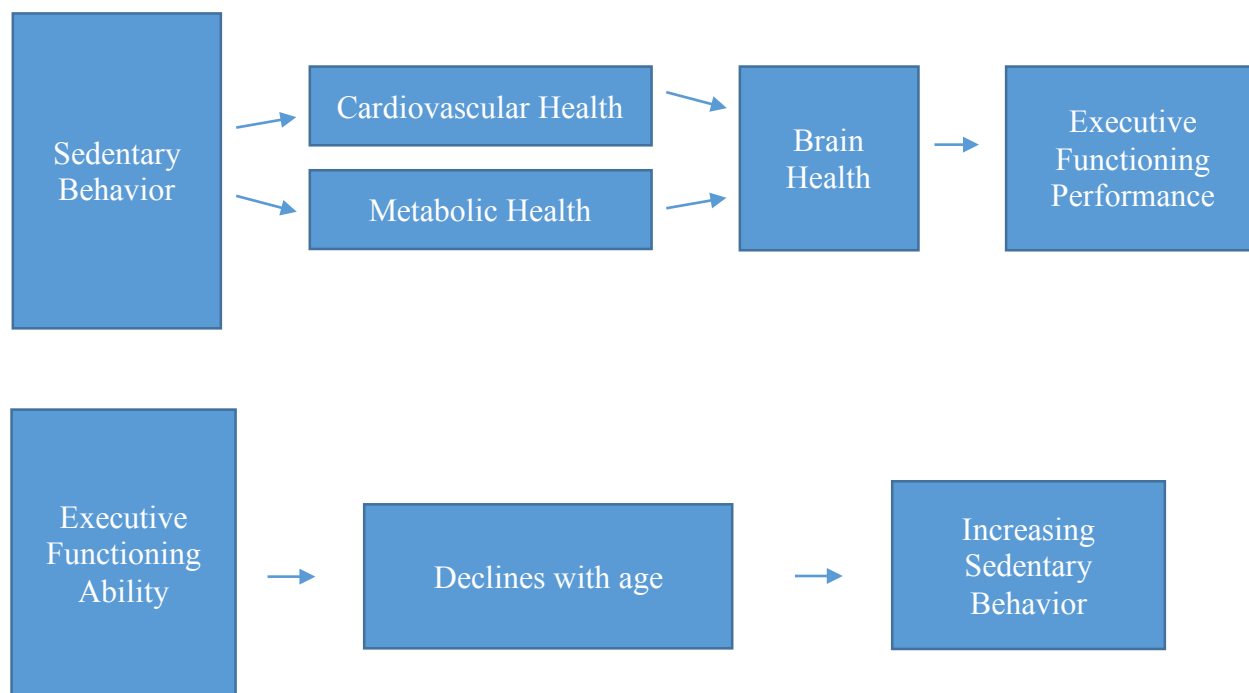


Figure 2. Theoretical explanations for a bidirectional relationship between executive function and sedentary behaviors

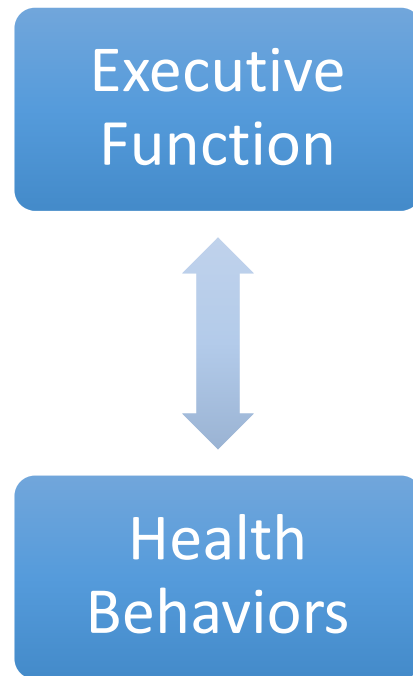


Figure 3. The bidirectional relationship between executive function and health behaviors

Table 1. Participant Characteristics

Variables	Total Sample <i>N</i> =80 <i>M</i> (<i>SD</i>)	Minimum	Maximum
Age (years)	73.24 (7.15)	60	92
Education (years)	16.54 (3.28)	10	25
BMI, kg/m ²	26.49 (4.35)	19.31	36.68
Men, <i>n</i> (%)	36 (45)	-	-
Race, <i>n</i> (%)			
White	73 (91.25)	-	-
Black	7 (8.75)	-	-
Dementia Status, <i>n</i> (%)			
AD	36 (45)	-	-
Non-AD	44 (55)	-	-

AD = Alzheimer's Disease

BMI = Body Mass Index

Table 2. Executive Function Factor Scores by AD Status

	Total Sample <i>N=80</i>	Non-AD <i>N= 44</i>	AD <i>N=36</i>
EF Factor Score			
Mean (SD)	.05 (1.4)	.91 (.58)	-.99 (1.38)
Range	-3.25 to 2.05	-.66 to 2.05	-3.25 – 1.12

Table 3. Inclinometer-Derived Sedentary Behavior Descriptive Statistics

Variables (Across One Week Period)	Mean (SD)	Minimum	Maximum	Proportion of Total Number of 30 Minute Sedentary Blocks
Total Number of 30- Minute Sedentary Blocks	101.63 (30.08)	40	165	-
Total Number of Screen Time Blocks	26.81 (19.95)	0	74	.25 (.16)
Television Watching Blocks	21.15 (19.79)	0	74	.19 (.16)
Computer Use Blocks	3.75 (6.80)	0	33	.04 (.06)
Multiple Screen Blocks	.81 (3.53)	0	27	.01 (.04)
Other Screen Blocks	1.10 (2.46)	0	16	.01 (.02)
Total Number of Non- Screen Blocks	61.36 (21.26)	17	115	.62 (.17)
Total Number of Mixed Screen and Non-Screen Blocks	9.25 (10.76)	0	49	.09 (.10)
Unknown Blocks	4.20 (10.11)	0	63	.04 (.09)

Table 4. Stepwise Regression Analysis of Types of Sedentary Behavior as Predictors of Executive Function

Variable	Model 1 Standardized Coefficients (β)	Model 2 Standardized Coefficients (β)
Age	.004	.021
Sex (Female = 0, Male = 1)	-.223*	-.139
Education	.193*	.184*
Race	.079	.080
Body Mass Index	.048	.004
Dementia Status (0 = Non-AD)	-.550**	-.490*
Interaction Term - AD*ScreenTime(proportion)	-.037	-.068
Television Watching (proportion)	-	-.018
Computer Usage (proportion)	-	.082
Multiple Screen (proportion)	-	.088
Other Screen (proportion)	-	.046
Mixed Screen & Non-Screen (proportion)	-	.227*
Unknown (proportion)	-	-.073
Model R ²	.545	.611

* $p < .05$, ** $p < .001$

Table 5. Stepwise Regression Analysis of Executive Function Scores as Predictors of Type of Sedentary Behavior

Variable	Model 2 – Proportion of Television Watching Standardized Coefficients (β)	Model 2 – Proportion of Computer Usage Standardized Coefficients (β)	Model 2 – Proportion of Other Screen Usage Standardized Coefficients (β)	Model 2 – Proportion of Multiple Screen Usage Standardized Coefficients (β)
Age	-.170	.227	-.265	-.148
Sex (Female = 0, Male = 1)	.150	.012	-.042	-.158
Education	-.183	.014	-.089	-.034
Race	.029	.073	-.063	-.042
Body Mass Index	.002	.123	.002	-.131
Dementia Status (0 = Non-AD)	.110	-.027	.080	.223
Interaction Term (AD*EF)	.417	-.206	-.164	-.054
Executive Function	-.627	.417	.150	.226
Model R ²	.300	.115	.099	.098

* $p < .05$, ** $p < .001$ using a Benjamini-Hochberg procedure for false discovery rate at .25

Variable	Model 2 – Proportion of Overall Screen Use Standardized Coefficients (β)	Model 2 – Proportion of Overall Non- Screen Use Standardized Coefficients (β)	Model 2 – Proportion of Mixed Screen & Non-Screen Use Standardized Coefficients (β)	Model 2 – Proportion of Unknown Standardized Coefficients (β)
Age	-.158	.167	-.002	-.029
Sex (Female = 0, Male = 1)	.104	-.172	-.072	.215
Education	-.200	.227	-.106	.043
Race	.037	.064	-.086	-.091

Body Mass Index	.016	-.018	.122	-.128
Dementia Status (0 = Non-AD)	.172	-.188	.270	-.244
Interaction Term (AD*EF)	.291	.078	-.602	-.007
Executive Function	-.368	-.195	1.116*	-.193
Model R ²	.213	.112	.246	.107

*p < .05, ** p < .001 using a Benjamini-Hochberg procedure for false discovery rate at .25